Notes on estimating X2, the distance from the Golden Gate to 2 ppt Salinity (km)

These notes were prepared to accompany an excel workbook (that will be available at the workshop if not before) containing 1930-2011 DAYFLOW and X2 data for use by IEP. The last two pages of these notes contain notes about X2 and outflow values available in CDEC and the now discontinued DWR/IEP HEC-DSS database. A compilation of CDEC outflow (1994-present) and X2 (2007-present) data is available.

NOTE: THE X2 EQUATION (equation 1, below) IS 20 YEARS OLD. MUCH MORE SALINITY AND FLOW DATA ARE NOW AVAILABLE THAN WHEN THE EQUATION WAS FIRST ESTABLISHED 20 YEARS AGO. THERE ARE SIGNIFICANT DISCREPANCIES BETWEEN X2 VALUES IN DAYFLOW AND IN CDEC. PROCEDURES FOR ESTIMATING X2 SHOULD BE REEVALUATED USING ALL CURRENTLY AVAILABLE DATA AND PERHAPS NEW MODELING APPROACHES.

X2 values in DAYFLOW (http://www.water.ca.gov/dayflow/documentation/dayflowDoc.cfm#Introduction):

According to the DAYFLOW documentation, "The 1994 Bay-Delta agreement established standards for salinity in the estuary. Specifically, the standards determine the degree to which salinity is allowed to penetrate up-estuary, with salinity to be controlled through delta outflow. The basis for the standards is a series of relationships between the salinity pattern and the abundance or survival of various species of fish and invertebrates. These relationships have been expressed in terms of X2, the distance from the Golden Gate to the point where daily average salinity is 2 parts per thousand at 1 meter off the bottom (Jassby et. al. 1995)."

DAYFLOW X2 estimates are available starting on October 1, 1996. In DAYFLOW, X2 is estimated using the Autoregressive Lag Model:

1. $X2(t) = 10.16 + 0.945*X2(t-1) - 1.487\log(QOUT(t))$
   where t = current day and t-1 = previous day

Daily X2 Estimates for the 1930-2011 time series in THIS WORKBOOK:

As in DAYFLOW and elsewhere, equation 1 and DAYFLOW's daily "Net Delta Outflow Index" (NDOI) values are used for all daily X2 estimates from 1930-2011. In contrast to previous X2 estimations, however, the outflow value is set to a fixed outflow of 50 cfs for days with negative net Delta outflow. The only exception is June 3 –June 5, 2004, when the X2 estimates given in DAYFLOW are used. See C2, below, for more information.

Additional information for estimating X2

A. Origin:

The X2 equation used in DAYFLOW was first published in Appendix A of the 1993 "Schubel report" (SFEP 2003). It was developed to "fill in the gaps" in a daily X2 time series that was developed by interpolating actual salinity measurements. The equation is an autoregressive

model with lag 1 and an additional variable, log outflow. It was fitted with outflow and X2 data for 1975-77 (>1000 data points). The Schubel report Appendix A was written in 1992 by Kimmerer and Monismith based on work by participants in the "Schubel workshop" and especially Alan Jassby who wrote Appendix 2 of the Schubel report. All later equations and publications are based on this work. In Appendix A of the 1993 Schubel report, Kimmerer and Monismith also give an equation for estimating monthly X2 values:

2. $X2(t) = 122.2 + 0.3278*X2(t-1) - 17.65\log(QOUT(t))$
   where t = current month and t-1 = previous month

B. Later X2 equations:

3. Jassby et al 1995: $X2(t)= 8 + 0.945*X2(t-1) - 1.5\log(QOUT(t))$
4. Jassby et al 1995 cited in Monismith, Kimmerer, et al (2002): $X2(t)= 10.2 + 0.945*X2(t-1) - 2.3\log(QOUT(t))$
5. Monismith, Kimmerer, et al (2002): $X2(t)= 0.919*X2(t-1) +13.57(QOUT(t)^{-0141})$
6. DWR Modeling Support Branch 1994: $X2(t)= 14.53 + 0.926*X2(t-1) - 2.192\log(QOUT(t))$

C. Problems with estimating X2 from outflow:

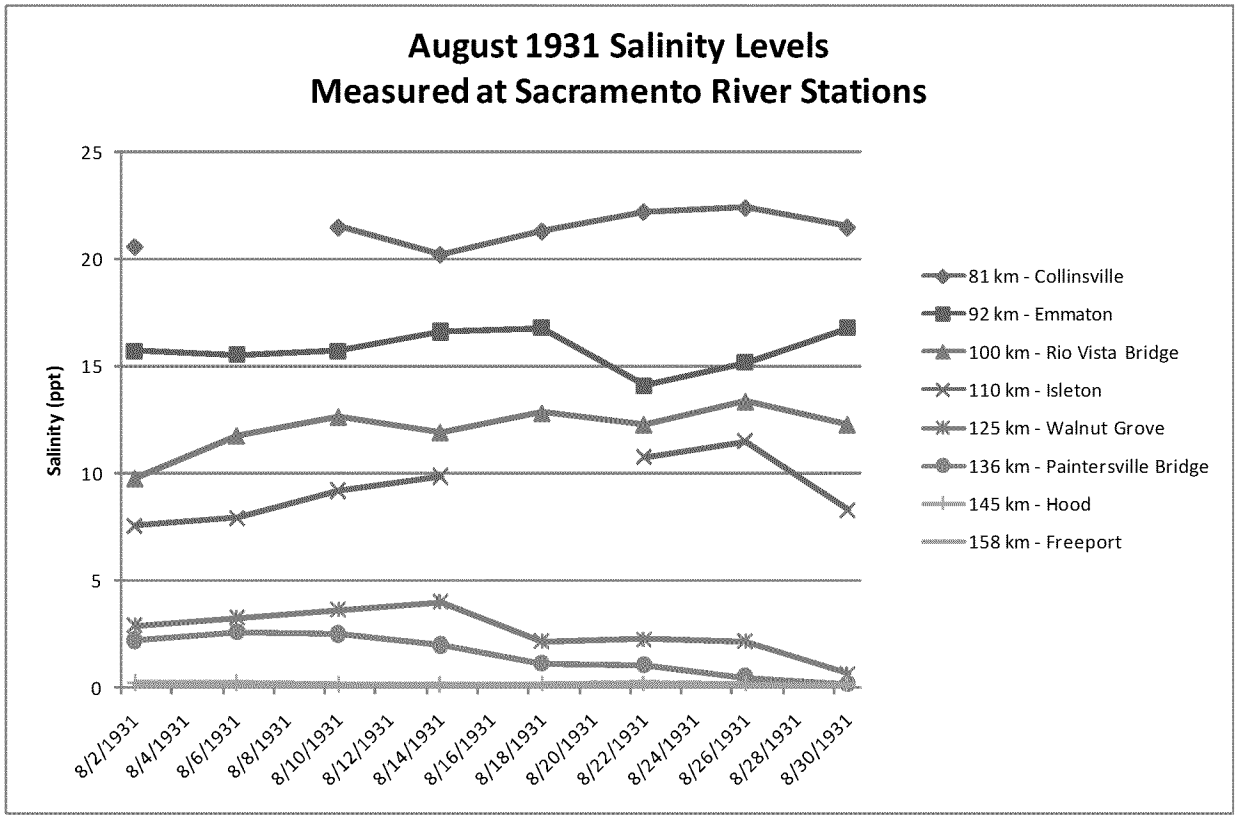
1. Equations 3., 4., and 5. don't give reasonable results – why? (see "X2Computation" worksheet)
2. Negative net Delta outflow: This happens fairly rarely, but it can be associated with extreme salinity intrusion during droughts. Due to spring-neap variations in flow, it is in reality perhaps also more common than the calculated Net Delta Outflow Index in DAYFLOW would suggest, see http://www.water.ca.gov/dayflow/ndoVsNdoi/ . In equation 1, X2 is estimated with log outflow. The log of a negative number does not exist. Moreover, daily X2 estimation requires an X2 value the previous day and gaps in the daily time series should thus be filled. In the Schubel report Appendix A, Kimmerer & Monismith noted that negative outflows were likely "being underestimated" in DAYFLOW (page A-6). They recommended setting "the value of log outflow for [days with negative outflow] to a minimum outflow of 316 cfs." They did not give a reason for this particular value. Following this recommendation produces what generally look like reasonable results.

   I decided, however, to use a substitution value of 50 cfs because this produces X2 estimates that correspond more closely to some observed salinity values, as follows. This should, however, be examined more carefully with additional data. Note that the choice of substitution value makes a difference only during the relatively rare negative outflow periods and a few months immediately following these periods.

   a. Net Delta outflow was negative during June 3-5, 2004, due to the Jones Tract levee break. Instead of using a substitution value, DAYFLOW used X2 values calculated from actual EC data measured at Pittsburg and Antioch, see http://www.water.ca.gov/dayflow/docs/2004comments.pdf . Estimating X2 with equation 1 with an outflow substitution value of 316 underestimated X2 during the three negative outflow days in June 2004 and for about 2 months afterward. An outflow

substitution value of 50 produced much better agreement, see X2Computation worksheet.

b. Net Delta outflow was often negative for prolonged periods in the extreme drought years of the 1930s. Salinity data for some of these years is available in a 1931 report (http://www.archive.org/details/variationcontrol27calirich) and DWR's Delta Atlas (http://baydeltaoffice.water.ca.gov/DeltaAtlas/04-WaterQuality.pdf) shows maximum salinity intrusions for 1921-1943. For 1931, the Delta Atlas shows that "1000 parts of chloride per million parts of water" (about 1.8 ppt salinity) were measured on the Sacramento River between Courtland and Hood, i.e. at approximately 140 km from the Golden Gate. The 1931 report shows salinity of >2ppt at Paintersville Bridge (approx. 136 km from the GG) in the first half of August 1931 (see Figure below). Using a negative outflow substitution value of 316 produces an average August 1931 X2 value of 116.5 km. A substitution value of 50 produces an average August 1931 X2 value of 137 km, i.e. much better agreement with the recorded salinity values.



References:

- 1931 Salinity report, http://www.archive.org/details/variationcontrol27calirich
- SFEP 1993 with Kimmerer & Monismith Appendix A, 1992, http://www.epa.gov/region9/water/watershed/sfbay-delta/pdf/Schubel-Report.pdf
- DWR 1994, http://www.swrcb.ca.gov/waterrights/water_issues/programs/bay_delta/wq_control_plans/1995wqcp/admin_records/part03/063.pdf
- Jassby et al 1995, http://sfbay.wr.usgs.gov/publications/pdf/jassby_1995_isohaline.pdf
- Monismith et al 2002, http://www-ce.stanford.edu/faculty/monismith/MonismithEtAl2002JPO.pdf
- DWR's Delta Atlas (http://baydeltaoffice.water.ca.gov/DeltaAtlas/04-WaterQuality.pdf

Daily X2 estimates on CDEC (pers com. Joni Hirabayashi, DWR, 9/12/2011)

In CDEC, daily X2 data starting in 2007 is available under the station name "CX2," see http://cdec.water.ca.gov/cgi-progs/stationInfo?station_id=CX2 .

On 9/16 and 9/27, 2011, CDEC posted the following description of the CX2 computation and data flags: The X2 value for station CX2 is linearly interpolated for the 2.64 uS/cm EC location among these four river mileages measuring from the SF Golden Gate Bridge: Martinez (MRZ, 56 km), Port Chicago (PCT, 64 km), Chipps Island (74 km) and Collinsville (CLL, 81 km).

"v" flag : the calculated value is less than 56.0 km or greater than 81.0 km.

On 9/12/2011, I obtained the following additional information from Joni Hirabayashi, DWR:

The X2 value for CDEC "station" CX2 (http://cdec.water.ca.gov/cgi-progs/stationInfo?station_id=CX2) is interpolated from the daily EC at the four X2 stations: Martinez (MRZ, 56 km), Port Chicago (PCT, 64 km), Mallard (MAL, 74 km) and Collinsville (CLL, 81 km). The formula was developed by engineers in DWR's O&M Operations Control Office.

CX2=(((2.64 – wEC) * (wkm – ekm))/ (wEC – eEC))+ wkm
Where:
wEC = daily EC of the westerly Station
eEC = daily EC of the easterly Station
wkm = kilometers of the westerly Station
ekm = kilometers of the easterly Station

Where EC =2.64 falls among the four stations determines which station pair is used. X2 values out of the 56 – 81 km range are not considered valid (Martinez EC < 2.64 or Collinsville EC > 2.64).

Daily Net Delta Outflow Index estimates on CDEC

Daily Delta Outflow starting in 1994 is available at http://cdec.water.ca.gov/cgi-progs/staMeta?station_id=DTO . There is no documentation posted about how this is calculated.

On 2/14/2012, I obtained the following information from Andy Chu, DWR:
"DTO" stands for DELTA TOTAL OUTFLOW. It is a calculated value, it is not measured. This term is commonly interchanged with "NET DELTA OUTFLOW INDEX", or NDOI, as reported in DAYFLOW. However, DTO values posted on the CDEC are typically NOT cross-checked on a real-time basis. More accurate NDOI numbers that are updated every business day are available at http://www.water.ca.gov/swp/operationscontrol/deltaops.cfm , "Hydrologic Conditions Summary."

CDEC DTO is calculated as follows:

NET DELTA OUTFLOW INDEX = INFLOW INTO DELTA - NET DELTA CONSUMPTIVE USE - CVP/SWP EXPORTS - CONTRA COSTA CANAL - BARKER SLOUGH PP

Where:
INFLOW INTO DELTA = SACTO RIV FREEPORT + SACTO CO WASTE WT TRTMNT + YOLO BYPASS + EAST SIDE STREAMS + MISCELLANEOUS - FORTHCOMING + SJ RIV FLOW VERNALIS

And:
CVP/SWP EXPORTS = CLIFTON COURT INFLOW - BYRON BETHANY DELIVERIES + TRACY PP TOTAL

One final note on net Delta outflow:

As mentioned above, "outflow" in DAYFLOW and CDEC is really a calculated "Net Delta Outflow Index" (NDOI), not a measured value. This is in contrast to "Net Delta Outflow," (NDO), which according to the DAYFLOW documentation (http://www.water.ca.gov/dayflow/ndoVsNdoi/) is a more direct estimate of daily average flow based on 15 minute USGS ultrasonic velocity meter (UVM) flow data from four stations. NDO is calculated as the sum of flows from these four stations:

NDO = Rio Vista + Three Mile Slough + Jersey Point + Dutch Slough
Where:
Rio Vista = Sacramento River at Rio Vista UVM
Three Mile Slough = Three Mile Slough at San Joaquin River UVM
Jersey Point= San Joaquin River at Jersey Point UVM
Dutch Slough = Dutch Slough at Jersey Island UVM

NDO data have been available in an U.S. Army Corps of Engineers' Hydrologic Engineering Center Data Storage System (HEC-DSS) database system that was maintained by the Department of Water Resources and the IEP. This database was recently discontinued. Archived historical HEC-DSS data is available for downloading as DSS data files at http://www.water.ca.gov/iep/products/data/dssnotice.cfm .